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# SEA WATER CORROSION TEST OF STAINLESS STEEL AND NICKEL BASE ALLOY CONDENSER TUBES

Research and Development Report 910027B
NS-643-078

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## ABSTRACT

Plain condenser tubes of austenitic stainless steels and nickel base alloys were tested at the Harbor Island Test Station in two model condensers of 20 tubes each. Natural sea water was pumped through the tubes at a velocity of 10 ft/sec. The condensers were operated on a 30-day "off-on" cycle during part of the test. All of the stainless steels were susceptible to pitting. Type 347 was damaged most, and Type 316 the least of the steels tested. There were no failures or serious deterioration of the nickel base alloy tubes. A Ni-Cr-Fe alloy was the least affected of the nickel alloys.

## ADMINISTRATIVE INFORMATION

Tests to compare and evaluate the various condenser tube materials described in this report were authorized by the following Bureau of Ships letters:

1. S46-5(646-330) NObs-45043 of 22 April 1948

2. S46-5(651) ser 651-506 of 2 June 1950

The work was assigned to NS-643-078.

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# REPORT OF INVESTIGATION

## INTRODUCTION

A test program was undertaken about nine years ago to compare various condenser tube alloys under simulated service conditions. The program was extended and modified to include materials of interest for use in closed-cycle systems. The accumulation of acidic exhaust gas condensates in closed systems would preclude the use of copper base materials for this application. Consequently, experimental condensers were constructed of materials offering more resistance to acid attack. These were tested at the Harbor Island Test Station to evaluate their performance on the sea water coolant side.

Certain other noncopper alloys had been tested previously. Plain titanium and Alloy D tubes (composition in Table 1) were reported to be completely immune to sea water corrosion and erosion at water velocities of 10 ft/sec, reference (a), and 20 ft/sec, reference (b). Reference (c) reported satisfactory performance of duplex condenser tubes of Type 304 stainless steel lined with 70-30 copper-nickel at 10 ft/sec water velocity.

The present report contains data on plain condenser tubes of austenitic stainless steels and nickel base alloys tested in model condensers for continuous and off-on cyclic exposure.

## MATERIALS AND METHOD OF TEST

The two model condensers described in this report (condenser unit Nos. 10 and 15) contained tubes 48" long. Materials and arrangements of the tubes in the condensers are shown in Table 1 and Figures 1 and 2. Tube changes in Condenser No. 10 are described under "Results of Test."

## Table 1

### Details of Condenser Construction

| Cond No. | Condenser Tube Alloy | No. of Tubes | Wall Thickness in mils* | Alloy Code | Location of Tubes** | Date of Tube Installation | Chemical Composition, % | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | C | Mn | Cr | Ni | Mo | Fe | Cu | Other |
| | Stainless, Type 316 | 1 | 49 | W | 15 | 11-5-50 | 0.07 | 1.71 | 18.97 | 13.42 | 2.20 | Rem | | |
| | Stainless, Type 316 | 1 | 35 | W | (1), 11 | 11-5-50 | | | | | | | | |
| | Stainless, Type 316 | 1 | 28 | W | (4), 9 | 11-5-50 | | | | | | | | |
| | Stainless, Type 316 | 2 | 22 | W | 12, 16 | 11-5-50 | | | | | | | | |
| | Stainless, Type 329 | 2 | 49 | X | 5, 13 | 11-5-50 | 0.07 | | 27.55 | 4.05 | 2.20 | Rem | | |
| | Stainless, Type 329 | 1 | 35 | X | 2, (20) | 11-5-50 | | | | | | | | |
| | Stainless, Type 329 | 1 | 28 | X | 6 | 11-5-50 | | | | | | | | |
| | Stainless, Type 329 | 1 | 22 | X | 14, (17) | 11-5-50 | | | | | | | | |
| | Stainless, Alloy A | 1 | 49 | Y | 7 | 11-5-50 | 0.04 | 0.85 | 17.24 | 17.63 | 0.10 | Rem | 0.44 | Si 0.29 |
| 10 | Stainless, Alloy A | 2 | 35 | Y | 3, 19 | 11-5-50 | | | | | | | | |
| | Stainless, Alloy B | 1 | 49 | Z | 8 | 11-5-50 | 0.05 | 1.00 | 20.39 | 29.97 | 2.26 | Rem | 3.41 | Si 1.09 |
| | Stainless, Alloy B | 1 | 35 | Z | 18 | 11-5-50 | | | | | | | | |
| | Stainless, Alloy B | 1 | 28 | Z | 10 | 11-5-50 | | | | | | | | |
| | Stainless, Alloy C | 2 | 28 | DBG | 1, 17 | 4-23-54 | 0.09 | 1.80 | 15.55 | 25.16 | 6.90 | Rem | 0.13 | Si 0.73 |
| | Ni-Fe-Cr-Mo Alloy*** | 2 | 49 | DCX | 4, 20 | 1-27-55 | 0.05 | 0.60 | 21.00 | 40.00 | 3.00 | 31.00 | 1.75 | Si 0.40 |
| | Stainless, Type 347 | 2 | 38 | AU | (4), (20) | 4-23-54 | 0.07 | 1.98 | 18.98 | 9.71 | 0.23 | Rem | | Cb 0.57 |
| | Stainless, Type 347 | 2 | 38 | AU | (4), (20) | 8-23-54 | | | | | | | | |
| | Alloy D*** | 2 | 20 | U | (4), (20) | 9-23-54 | 0.10 | | 16.5 | Rem | 17.0 | 6.0 | | W 4.25 |
| | Ni-Cu Alloy | 3 | 49 | T | 1, 8, 15 | 8-24-54 | | 0.91 | | Rem | | 1.64 | 30.14 | |
| | Ni-Cu Alloy | 4 | 35 | T | 6, 13, 18, 19 | 8-24-54 | | 0.89 | | Rem | | 1.62 | 30.13 | |
| 15 | Nickel | 3 | 49 | S | 2, 7, 20 | 8-24-54 | 0.04 | 0.19 | | Rem | | 0.16 | 0.08 | |
| | Nickel | 4 | 35 | S | 3, 5, 12, 16 | 8-24-54 | 0.03 | 0.20 | | Rem | | 0.15 | 0.12 | |
| | Ni-Cr-Fe Alloy | 6 | 49 | AO | 4, 9, 10, 11, 14, 17 | 8-24-54 | | 0.24 | 15.62 | Rem | | 6.80 | 0.11 | Al 0.50 |

*All tubes were 5/8" OD except Stainless Alloy C, which was 3/8" OD. Type 316 bushings were used with Alloy C tubes.

**Tubes in parentheses were replaced before termination of test.

***Nominal composition; not analyzed.

| Type - Stainless Steel | Tubes |
|---|---|
| 316 | 9, 11, 12, 15, 16 |
| 329 | 2, 5, 6, 13, 14 |
| Alloy A | 3, 7, 19 |
| Alloy B | 8, 10, 18 |
| Alloy C | 1, 17 |
| Ni-Fe-Cr-Mo | 4, 20 |

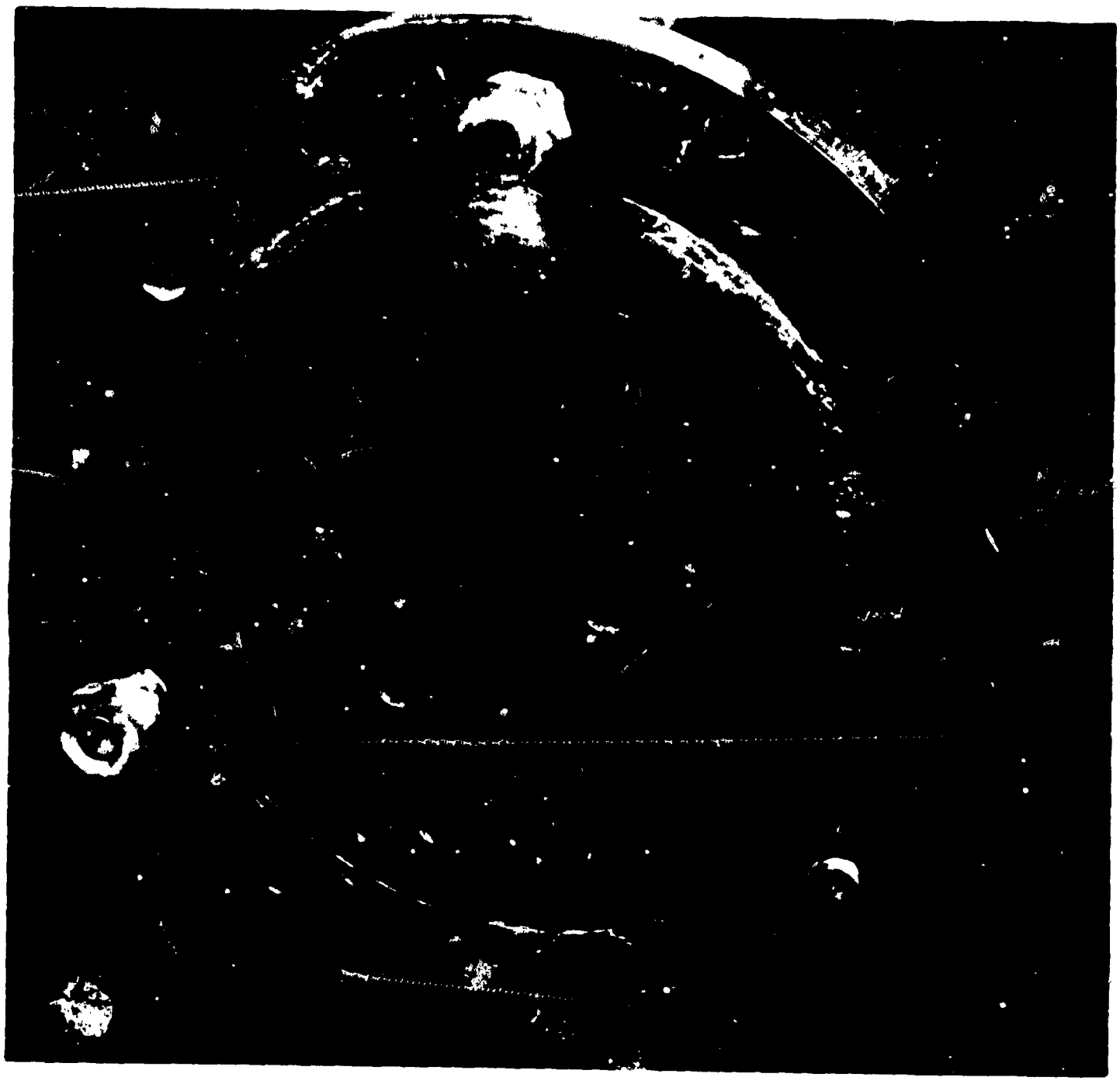

Figure 1

Inlet Tube Sheet, Condenser No. 10
Austenitic Stainless Steel Tubes
Type 316 Tube Sheet

| Nickel Base Alloys | Tubes |
|---|---|
| Ni-Cu | 1, 6, 8, 13, 15, 18, 19 |
| Nickel | 2, 3, 5, 7, 12, 16, 20 |
| Ni-Cr-Fe | 4, 9, 10, 11, 14, 17 |

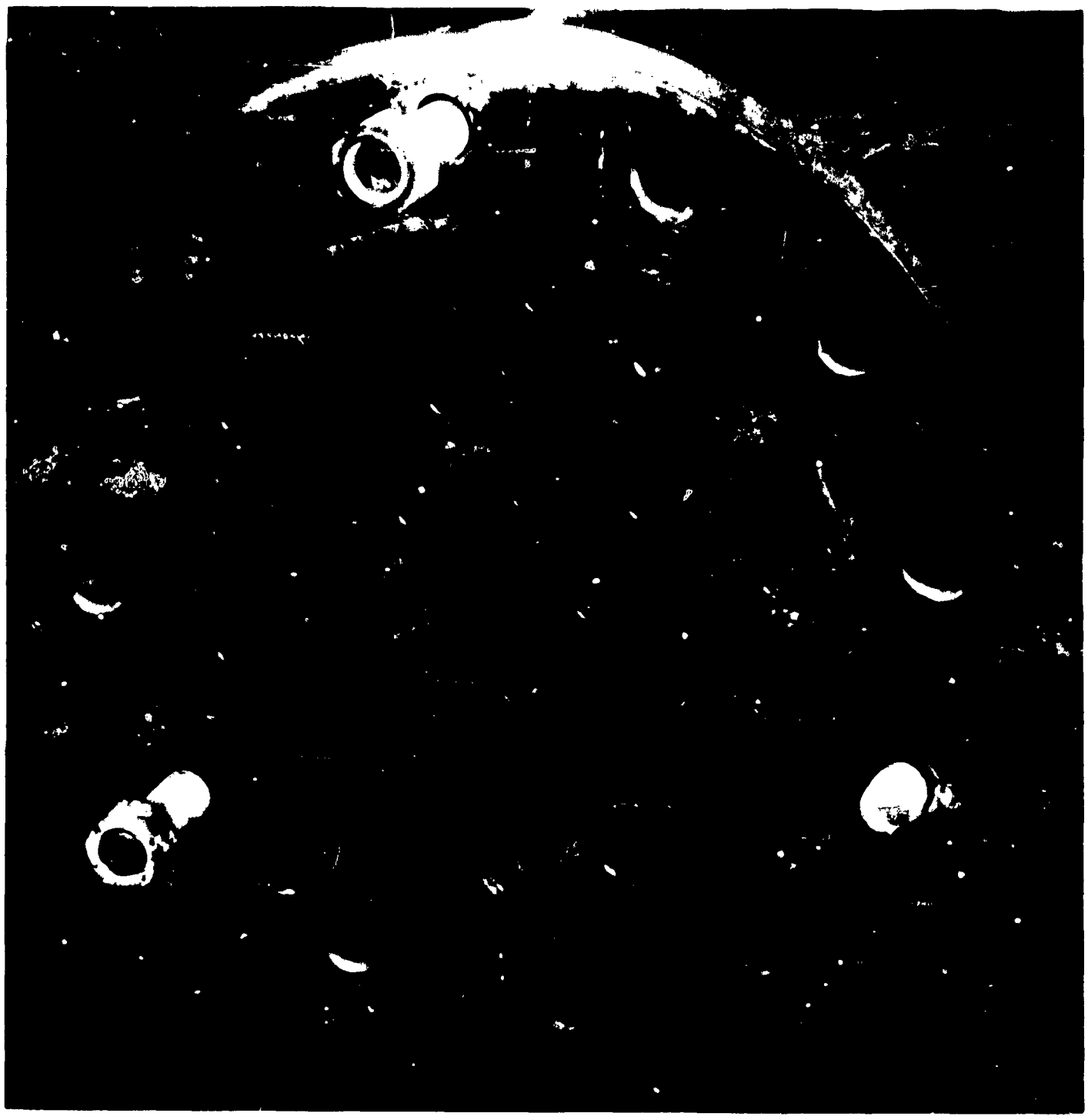

Figure 2

Inlet Tube Sheet, Condenser No. 15
Nickel Base Alloy Tubes
Ni-Cu Tube Sheet

Both condensers were operated continuously for a part of the time, and on a 30-day off-on cycle for the remainder of the time. Normal water flow during full operation was 140 gpm. Flow was regulated to 10 gpm during the "off" period of the off-on cycle. Operational data for the condensers are shown in Table 2. Operating times are recorded as the number of months between dates of installation and removal, less the actual time the condensers were shut down for inspection, power failures, etc.

Table 2

Operational Data

| | Condenser No. | |
|---|---|---|
| | 10 | 15 |
| Tube sheet material | SS, Type 316 | Ni-Cu alloy |
| Waterbox material* | Ni-Cu alloy | Ni-Cu alloy |
| Date installed | 11/5/50 | 8/24/54 |
| Date removed | 7/22/58 | 7/22/58 |
| Total time installed, months | 92-1/2 | 47 |
| Down time, months | 8-1/2 | 5 |
| Actual operating time, months | 84 | 42 |
| Dates of cyclic off-on operation | 12/9/52 to 9/16/57<br>1/29/58 to 7/22/58 | 1/29/58 to 7/22/58 |
| No. of off periods in cyclic test | 29 | 3 |

*Waterboxes insulated from tube sheets.

## RESULTS OF TEST

Examination of the experimental condensers indicated conditions described in the following paragraphs.

### Condenser 10

Condenser No. 10 originally contained tubes of four austenitic stainless steels, Type 316, Type 329, Alloy A, and Alloy B in a Type 316 tube sheet. The tubes were rolled, but as a precaution against splitting, the ends were not flared. Solder-wiped Ni-Cu alloy heads were installed and insulated from the tube sheets.

The first tube failure, Type 329 tube in Position 20, occurred after two years of operation and after two off periods of the off-on schedule. This tube developed a hole 2" from the inlet end. It was finally

replaced with a Type 347 tube in April 1954. Other tube changes made at that time included the replacement of Type 316 with Type 347 in Position 4, and replacement of Type 316 and Type 329 with stainless Alloy C in Positions 1 and 17.

After three months of operation, the Type 347 tube in Position 20 was perforated 34" from the inlet end. A hose clamp was placed around the tube to prevent leaking. The test was continued for another month, when the other Type 347 tube failed in Position 4.

The two failed Type 347 tubes in Positions 4 and 20 were replaced on 23 August 1954 with two new tubes of the same composition. Both of these tubes became perforated in one month at 10 ft/sec ("on" period) and were replaced with Alloy D tubes. These remained in service until January 1955 with no evidence of deterioration. Two Ni-Fe-Cr-Mo alloy tubes, which replaced the Alloy D tubes in Positions 4 and 20, were in operation from January 1955 to termination of the test on 22 July 1958.

Of the remaining stainless alloy tubes originally installed in Condenser No. 10, one Alloy B tube in Position 8 developed a leak after five years, but was not removed from operation.

The inlet tube sheet and tube ends of Condenser No. 10, at the termination of test, are shown in Figure 1. Both Type 316 inlet and outlet tube sheets exhibited crevice corrosion at the gasket seal to a maximum depth of 1/16". All tube seats in the inlet sheet showed some degree of crevice corrosion.

The tubes were split and examined visually, in most cases under magnification, to determine significant differences in performance. Observations are recorded in Table 3. Waterside deterioration was practically nil on the tubes, except where barnacles and other marine life were attached and caused crevice corrosion pits.

Type 329, Alloy A, and Alloy B tubes exhibited more crevice corrosion at the tube sheets than the other alloys. The leak reported in the Alloy B tube in Position 8 could not be attributed to any perforations in the tube wall, and it is assumed the tube was leaking from crevice corrosion pits at the sheet.

## Condenser 15

Condenser No. 15 was constructed with tubes of three nickel base alloys. The tubes were rolled and flared in Ni-Cu alloy tube sheets.

Solder-wiped Ni-Cu alloy heads were installed and insulated from the tube sheets.

There were no tube failures in this condenser and, consequently, no tube changes were made in 42 months of actual operation. Figure 2 shows the inlet tube sheet and tube ends at the termination of test. After acid cleaning, the sheet exhibited moderately light effects of erosion.

All tubes were split for visual examination of the waterside, and deterioration was found to be insignificant except for minor inlet end impingement exhibited by the Ni-Cu tubes. The pitting described in Table 3, for the most part, represented a local removal of the protective corrosion film. (See Table 3, page 10.)

## CONCLUSIONS

The results obtained from salt water operation of these model condensers led to the following conclusions.

All of the stainless steel alloys in this test were susceptible to salt water pitting. Type 347 was the most vulnerable, with wall perforation occurring within one month on several tubes. One Type 329 tube failed from pitting after two years of operation, although the remainder of the Type 329 tubes did not exhibit serious pitting damage and appeared to be more prone to failure by crevice corrosion at the tube sheet. Type 316 was perhaps the least susceptible to pitting attack and crevice corrosion.

The attachment of barnacles or other marine life to the tube walls of stainless steel promoted crevice corrosion.

There were no failures or serious deterioration of the tubes in Condenser No. 15. Of the nickel base alloy tubes, the Ni-Cr-Fe alloy was the least affected by salt water corrosion-erosion.

## REFERENCES

(a) E.E.S. Rpt 040027 of 9 Feb 1955 — 56 703
(b) E.E.S. Rpt 040020C of 16 Dec 1957 — 0
(c) E.E.S. Rpt 910027A of 21 Mar 1958 — 0

Table 3

Condition of Tubes After Test at 10 ft/sec

| Tube Alloy | Wall Thickness Mils | Location of Tube | Months in Test | Condition of Tube |
|---|---|---|---|---|
| SS, Type 316 | 49 | 15 | 92 | Few small pits and slight impingement attack at inlet end found under magnification. |
| | 35 | 11 | 92 | Same as Tube 15 with light crevice corrosion at tube sheet. |
| | 35 | 1 | 41 | Replaced without failure. |
| | 28 | 9 | 92 | Same as Tube 11. |
| | 28 | 4 | 41 | Replaced without failure. |
| | 22 | 12 | 92 | Same as Tube 15. |
| | 22 | 16 | 92 | Same as Tube 11. |
| SS, Type 329 | 49 | 5 | 92 | Few scattered pits of less than 1/2 mil depth, light general attack, slight inlet end impingement under magnification, fairly severe crevice corrosion at tube sheet. |
| | 49 | 13 | 92 | Same as Tube 5, except no crevice corrosion at tube sheet. |
| | 35 | 2 | 92 | Very light general attack, slight inlet end impingement under magnification, crevice corrosion at tube sheet. |
| | 35 | 20 | 41 | Failed by perforation. |
| | 28 | 6 | 92 | Same as Tube 5, except light crevice corrosion at tube sheet. |
| | 22 | 14 | 92 | Same as Tube 5, except very severe crevice corrosion at tube sheet. |
| | 22 | 17 | 41 | Replaced without failure. |
| SS, Alloy A | 49 | 7 | 92 | Few scattered pits of less than 1 mil depth, light general attack, slight inlet end impingement under magnification. |
| | 35 | 3 | 92 | Few scattered pits of less tha 1 mil depth, slight inlet end impingement under magnification, light crevice corrosion at tube sheet. |
| | 35 | 19 | 92 | Same as Tube 7, in addition to crevice corrosion at tube sheet. |
| SS, Alloy B | 49 | 8 | 92 | Scattered pinhole pitting, maximum depth of measurable pits 13 mils, slight inlet end impingement under magnification, severe crevice corrosion at tube sheet. |
| | 35 | 18 | 92 | Scattered pits of less than 1 mil depth, inlet end impingement under magnification, fairly severe crevice corrosion at tube sheet. |
| | 28 | 10 | 92 | Same as Tube 18, except light crevice corrosion at tube sheet. |
| SS, Alloy C | 28 | 1 | 51 | Scattered shallow pitting of less than 1 mil depth. |
| | 28 | 17 | 51 | Same as Tube 1, except pitting under barnacles to maximum depth of 13 mils. |
| Ni-Fe-Cr-Mo Alloy | 49 | 4 | 42 | Scattered pitting of less than 1/2 mil depth, dark grey film after nitric acid cleaning. |
| | 49 | 20 | 42 | Scattered pitting of less than 1/2 mil depth, several pits under barnacles to maximum depth of 23 mils. |
| SS, Type 347 | 38 | 4, 20 | 4 | One tube failed by perforation in 3 months and one in 4 months. |
| | 38 | 4, 20 | 1 | Both tubes failed by perforation in one month. |
| Alloy D | 20 | 4, 20 | 4 | No damage. Replaced with Ni-Fe-Cr-Mo. |
| Ni-Cu Alloy | 49 | 1, 8, 15 | 47 | Shallow pits of less than 1/2 mil depth, etched appearance where film was removed, some inlet end impingement. |
| | 35 | 6, 13 18, 19 | 47 | Large shallow pits of not more than 1 mil in depth, etched appearance where film was removed, inlet end impingement. |
| Nickel | 49 | 2, 7, 20 | 47 | Scattered shallow pitting of less than 1/2 mil depth. |
| | 35 | 3, 5 12, 16 | 47 | Large and small shallow pits of less than 1/2 mil depth. |
| Ni-Cr-Fe Alloy | 49 | 4, 9, 10 11, 14, 17 | 47 | Like new, few small, shallow pits of less than 1/2 mil depth. |